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A Study of Research and Development in Environmental Engineering Using System Approach

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The real name of the devil is sub-optimization, finding out the best way to do something which should not be done at all.

Kenneth Boulding, 1970

I. INTRODUCTION

This paper will establish a systems conception for problems of the environment which will serve as foundation for eleven recommendations upon the ways in which research and development efforts in this area may beneficially be redirected. The opening section will argue that scientific and managemental approaches to the environment have become fettered by a narrowness of perspective that has limited their potential contributions. We argue that the viewpoints adopted in directing and performing research activities should

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be broadened 1) in geographical extent, 2) in conceptual reach, 3) to embrace more environmental systems, 4) to consider natural systems explicitly, 5) to take into account the interconnections of the environment with other social systems, and 6) to heed the social system through which the environment is maintained.

The following section presents three models of the encompassing social system as it affects the environment. The models feature: a micro-economic view of the firms and households which may despoil the environment; the basic political mechanisms through which environmental wrongs can be set right; and the network of information flows necessary to manage the environment. These systems are examined to identify their weaknesses and to discover points of leverage where improvements may be effected. Special attention is devoted to the factor of incentives, to the distributional equity of proposed policies, to the possibilities for direct management of environmental systems, to the need for preparation in advance of environmental disasters, to the establishment of standards, and to environmental monitoring.

We finally identify environmental responsibilities at the international level which crucially require fulfillment.

It is said that any analyst called upon for counsel will recommend the application of people like himself. This paper may be vulnerable to that charge. Research and development have been here interpreted to include analysis and the recommendations below strongly call for broad, multidisciplinary action approaches. Yet, within the sphere of systems analysis, it is important to notice what we have omitted from our recommendations. We have not urged any further activity to develop models for existing managemental systems. Although this has been an important area of systems analytic contribution in the past, we judge here that this work has progressed beyond the point of diminishing returns and should be deemphasized, but not eliminated. Nor have we urged that any stress be placed upon isolated systems research performed by the lone analyst closeted, perhaps with a computer, from the organizational systems that can implement his work. While recognizing the need for a solid foundation of methodological work, we argue that the bulk of analytic effort now should go toward bridging the gap between analysis and implementation. To do this, the analyst must consciously direct his energies to policy areas where they are most needed. He must adopt the complete perspective of his client--not excluding any factors on the basis of analytic unsuitability--and he must present his findings and conclusions in forms designed to facilitate their eventual implementation.

The perspective of this paper is that of multidisciplinary systems analysis geared toward concrete applications. The sections below do not purport to represent expert understanding of the technical aspects to environmental engineering. We will argue below that special efforts by non-technical analysts and decision-makers to understand the present and future capabilities and limitations of technology are necessary if we are to manage our environment wisely. Such an effort has here been made. The many suggestions put forward below for the redirection of research and development are, however, based not so much upon a thorough technological grasp of the area as upon a perception of neglected opportunities. We will point out entrees for analysis and research with special promise of benefit within existing social systems that have not been pursued. The best tactical approach to a given research area must be selected by the technical specialist. We attempted here only to develop a strategic outlook through which areas with insufficient tactical inquiry may be identified.

II. THE BROADER VIEW

The Widening Crisis

Every action of environmental impairment has the characteristic of neglecting the embracing system in which the action is ultimately embedded. The housewife who buys her ice cream in plastic, disposable containers; the farmer who enriches his soil with phosphate fertilizers; the industrialist with his smokestacks belching sulfurous clouds do not want to make their world less liveable. They are doing what is best for the sub-systems they manage--the home, the farm, and the factory. Were the world of infinite size or their actions rare and isolated events in the given world, no problems would arise. Yet it is the aggregation of such acts in surroundings without infinite capacity to absorb their peripheral effects that causes environmental harm.

We argue here that a similar process of sub-system optimization is limiting the utility of our efforts to protect our environment. At one time, a primary remedy to pollution problems was greater physical dispersion--carting garbage farther away, piping sewage to more distant rivers, building taller smokestacks. As townships and regions grew, it came to pass that such measures only inflicted the harm of their wastes upon each other: the skies and rivers that would have been if other communities had not taken the same actions did not return. The solution to the local problem of pollution became one causal mechanism in a new environmental crisis an order of magnitude larger.

Today there is growing awareness that too narrow approaches to resolve environmental problems create further, more serious problems through the same process of sub-optimization that motivated the polluters themselves. The dominant characteristic of the contemporary environmental emergency is, to this observer, an ever larger complex of system interactions. The actions taken to improve one system now have more and more frequently the effect of harming others. To resolve the crisis, or just to endure it better, our understanding and our perspective of the problem must grow.

The Geographical Reach of Pollutant Systems

It was once an adequate solution to transport wastes farther away. Later, improved planning and scheduling of pollutant discharges provided relief for the environment. Today we find that these methods do not suffice. Either the cost of transporting the materials beyond the domain of the polluted system is prohibitive or the finiteness of our globe itself restricts possible solutions. Thermal pollution has now not only heated up significant stretches of the Rhine, but threatens to melt polar ice. The growth of the city and its pollution has already produced heat islands and associated problems that are quantitatively and qualitatively different from those with which we previously were familiar. While it still is adequate to regard sulfur dioxide as a local or regional problem, the global concentration of carbon dioxide may soon reach critical dimensions. Our effects on the atmosphere may already have caused a significant change in planetary albedo with unknowable consequences. Experiments have shown that continued discharge of radioactive wastes into the oceans can impair the viability of fish eggs at minimal concentrations. To find measures that will palliate and help to resolve the present crisis, we must expand our view to take in its global dimensions.

Recommendation 1: Environmental problems must be conceived in the scope of ever larger physical systems. The efforts of the engineer to develop new technologies must be addressed to broader systems as must also be the analysis that would make best use of present and developing technologies.

Governments must not parcel out responsibility so that researchers can feel satisfied in treating mere corners of the crisis. Analysts should direct their attention to smaller systems only when assured that the combined external effects of these systems do not comprise a problem in themselves.

The Conceptual Extent of Environmental Systems

Too often in the past, men with limited responsibilities performed in agencies of bounded roles. They managed or acted within sub-systems of the environment. In combating the previous crises of the environment, the inefficiencies resulting from the cramped horizons of decision-makers were not serious. It is characteristic of the contemporary situation that the harmful side effects of such sub-optimizations are themselves approaching crisis proportions.

The area of water resources illustrates the needed broadening of perspective. Once it was enough to worry about one's reach or tributary to discharge capably the responsibilities of water management. It came about that the upstream effluent grew so large that no actions downstream could make its ambient water tolerable and that so many communities used the nearest large lake as panacea to their disposal problems that the lake descended from unpleasant to toxic. It was realized that water systems managers, to attain sufferable outcomes, had to think in terms of larger systems. The first broadening of scope was physical. Water resource departments were realigned so that domains of action became river systems and watersheds. And their results improved. Men are coming to see that they must consider seas, and oceans, and--for some problems--all the surface waters of the world if they are to manage well their environmental heritage.

Yet, in many areas, such geographical breadth of understanding is not enough. The methods of analysis that were adequate to understand the reach could adopt special aggregating algorithms to become adequate to understand the estuary. But computerized aggregation techniques were not enough to extend this comprehension to the wetlands. It came to be perceived that marshlands had profound effects upon surface waters and in turn were affected by them. Ground water is approximately equal in volume to surface water and exchanges between the two sub-systems are continual and significant. To conceive of the problem in terms of the surface waters alone was to neglect vital processes as well as handles to the problem situation.

Recommendation 2: Environmental analysis must extend its purview to cover sub-systems related to its individual problem situation.

Lakes cannot always be studied apart from the stream networks flowing into them. Seas cannot be isolated from the lake and riverine systems that feed them. Surface water sub-systems belong to an embracing system including wetland water, ground water, and atmospheric water. Analysis, if it is to grasp the entire problem, must devote its attention to integrating the techniques used for the decomposed parts of the problem. Special care must be given to interfaces between the sub-systems: to understand the exchanges between surface and ground waters as between the troposphere and the stratosphere. Techniques should be developed for managing the composite system.[1]

The Linkage of Environmental Systems

Research disciplines and managerial praxis have evolved to handle such aspects of the enviromental problem as air pollution, water pollution, solid waste disposal, and waste heat. These methods are, as we have argued above, hampered by their narrowness of focus within their problem area. They are limited, too, by their failure to take into consideration other pollution systems as they optimize their own. Thus, reductions to air pollution can be gained at the cost of further befouling our waters. Nuclear power plants replace coal-burning generators and cut air pollution at the cost of increased waste heat and radiological hazard. Disposal of solid wastes destroys valuable wetlands while the alternative of burning plastics releases noxious fumes to the air.

> Recommendation 3: Analysts, engineers, and managers must consider environmental systems taken as a whole. If their attentions are directed toward measures applied within sub-systems, their own incentives should be such that the measures they prescribe or enact benefit the complex of systems taken together.

Understanding Natural Systems

As the magnitude of the harm man can do his environment grows, it no longer can be assumed that natural systems will endure and absorb man's actions and return to their original states. Increasingly, it becomes important to understand our environment as a synecological complex of systems. This approach enables us to see the consequences of our consequences through a chain of events that may lead to restoration of the original system or may, depending upon the stochastic interactions of events, reach new equilibria. If the insult to the environment is continually repeated, reversion to the initial state of affairs may be impossible.

> Recommendation 4: Research into the natural environment should investigate its systems properties.

An immediate benefit will be to increase the range of policy options as we learn to manipulate natural systems. The value--but also the risk--of such policies has been often illustrated through the use of natural predators to control pest populations. Today the systems understanding of nature is needed to anticipate better the major short- and long-term consequences of our actions. When we affect one sub-systemic process we may fundamentally alter the entire system. Long-term environmental damage; planned short-term shocks --such as refuse dumping during construction periods--and random accidents--such as oil spills--all have effects that reverberate through natural systems. Only by understanding better the systems themselves will we learn their resilience to various shocks--measured by their speed of reversion to the status quo ante and by their persistence when drastically altered or reduced. We can discover which of our actions necessitate the greatest change in natural systems and which have irreversible consequences. We should learn which actions we can take to minimize the effects of rare catastrophes and which to speed their return to healthy equilibria--if not to their original state.

Interconnections with Other Social Systems

Systems which pollute too often view their own processes as of such importance that the concomitant pollution is sensed as an inevitable by-product and thereby as an inalienable right.

But environmental advocates peddle a sibling falsehood: that the panacea to the environmental crisis is the elimination of pollution. Their too simple view of the situation will not admit that any good is served by processes that pollute. Nor do they see that improvements can be gained by means other than the absolute reduction of pollution--for instance, by better management of polluted systems or by better adaptations of men and other life to them. There are few who would not prefer a totally undespoiled environment, but few are those who would forego the commercial products, the modes of transportation, and the low-cost, high quality food--all brought about in part by polluting technologies.

The solution to the environmental problems created by the internal combustion engine is not to curtail all travel by automobiles. Nor is it, on the other hand, to resign ourselves to foul air as inevitable. We must rather take steps to lessen the harm done by all air pollution and, at the same time, act to reduce the level of pollution. We may find technological means to minimize pollutant emissions per passenger-mile and we can reduce the number of miles traveled by each person. A parallel effort should be made in industry: pollution per manufactured unit should be reduced and the number of units produced may be decreased.

We must recognize, however, that there are costs in cutting back the polluting processes that partially offset our gains in reducing pollution levels. We should use our technological ingenuity and our social management expertise to curtail polluting processes to the point where, at the margin, the environmental gain from reducing pollution further is exceeded by its costs. In many parts of the industrialized world, neither a creative enough approach has been taken in selecting policies to reduce pollution nor have the policies adopted been carried to the point at which their cost at the margin equals their gain.

Man will, for the foreseeable future, live in an impaired natural environment. Parallel to his efforts to reduce the damage he does his surroundings must be attempts to adapt to his imperfect world. If the river of a city becomes septic from advanced decomposition processes, partial solutions to the problem will be vigilance in water supply purification and the construction of municipal swimming pools. Similarly, palliatives to severe smog will be gas masks, or improved medical treatment for coronary problems resulting from air pollution, or movement of the most vulnerable populations from heavily polluted areas, or weather modification to induce dispersing winds.

A related family of policies is designed to improve management of polluted systems. It may be less costly to cleanse a river of sulfates derived from acid mine drainage by dumping lime into it than by stopping all effluence from point sources. Yet we should not consider sets of environmental remedies in isolation from alternative levers upon the system. All available handles to the problem should be considered before settling upon one set as the optimum solution. In the case of any polluted system it is possible that either reduction of the polluting process, or management of the polluted system, or better adaptation to the system may be the sagest policy. More often, a combination of the three strategies will produce the best result.

Recommendation 5: To improve our environment it is necessary to take into consideration the factors that lead men to pollute.

The problems of phosphate pollutions from fertilizers or of pesticide run-off cannot be considered in isolation from the system of demands placed upon the agricultural sector and from the manifold of technologies available to the farmer.

Recommendation 6: As partial remedies to the impairment of our environment, measures which manage portions of the degraded environment and measures which help man and other species to adapt to it merit greater consideration than they have received heretofore.

The Societal System for Maintaining the Environment

Placing Priorities on Goals

Just as few would oppose the restoration of our environment to a totally undespoiled state, so too would few object to the supersonic transport plane, could they be assured that it entailed no harmful side effects. But, given the conflict of goals, we must choose among them. It was argued above that measures for reducing pollution should be pursued only so long as their marginal gains exceeded the marginal costs. But this implies that values be placed upon each: upon the cost of greater inconvenience when travellers are forced to less polluting modes and upon the gains in cleaner air. All laws regulating the environment implicitly place values upon these alternative goods but this is done haphazardly and with frequent self-contradiction. A more systematic way of allowing the populace to express its preference is necessary if we are to manage our environment efficiently.

This will not be easy. In many societies, it is unclear just who has the right to make decisions, or, if there are many parties to a decision, what rule for obtaining a decision should be followed. Insoluble conflicts often prevent decision and in effect amount to a decision to maintain the status quo. Our governmental machinery, developed patiently over the course of centuries, has not learned to cope with the unique organizational problems raised by the present crisis of the environment. As a result, the difficulties in achieving decision and the lack of guiding precedents contribute much to our environmental woes. Society must improve its mechanisms for enabling whichever combinations of individuals are deemed to exercise the right of decision to follow the dictates of their collective will. The dearth of international decision-making bodies makes this problem especially urgent in global scale crises: carbon dioxide release, pesticide contamination of the oceans, and the threatened extermination of fish species.

The situation is made more difficult by the complexity of policy options. In most instances it is wisest neither to place a blanket prohibition upon polluting actions nor to permit them to continue unchecked. Yet intermediate policies are not easily formulated and their wise implementation requires technological understanding of the processes involved. Without such understanding, it is easy to perpetuate follies: to order actions that are prohibitively expensive; to mandate policies that contribute minimally to improving the environment; to ignore better technological alternatives.

The problem is especially acute in instances where short-run gains compete against long-run losses or incur long-run uncertainties. Increasingly it is being argued that near-term measures to make city life more tolerable merely postpone an inevitable crisis and augment its probable severity. Birth control, whether mandatory or voluntary, is a policy rarely advocated for short-term advantages but supported strongly by some as the only solution to the long-term problem. We should not here become embroiled in the different philosophical problems bearing upon these issues. We contend only that long-term issues of this nature are all too poorly understood and that scientific analysis must play a role in explicating and clarifying the distant consequences of decisions which do not take those consequences into account. The explanations should be addressed to public officials,[2] to electorates, and to individual citizens whose cumulative acts carry long-run risks.

> Recommendation 7: Better means must be found to communicate to the populace and to governmental decision-makers the range of complex factors that should bear upon their actions.

These include describing all important aspects of available technologies, assessing future technologies, and predicting the indirect effects of our actions. Analysts should make use of modern techniques for computation, communication, and display in the effort to clarify not only the parameters of the action choice but also the methods of analysis itself. This will not be an easy step for the experts inasmuch as it is designed to dispel their aura of mystery and thereby their mystique. The reward for these sacrifices will be to enhance the potential contribution of analysis to society. A caveat must be appended to this recommendation. Analytic techniques have not advanced to the point at which they can make all things clear, even to the analysts themselves. An important objective of the efforts to make the counsel, predictions, and methods of analysis more lucid is to show better the areas where uncertainty persists. Today's distrust of the analyst is largely derived from yesterday's presentations which clouded his methods and brooked no doubt about his conclusions.[3] When helpful, non-analytic decision-makers should be presented with alternative analyses that advocate competing policy options as a means of delineating better the zone of uncertainty. In the environmental problems of today, understanding the uncertainties involved is at least as important as understanding the sureties.

Achieving our Goals

It is possible for society to formulate its priorities as specific policy choices: for instance, by decreeing via plebiscite that one-passenger cars be banned from the freeways at peak-load hours. Perhaps this will be the clearest and least deceptive way for the electorate to exercise its will. More often, though, plebiscites cannot be arranged rapidly enough, nor structured well enough, nor can the electorate be well enough informed to make this a permanent mode of operation. Instead, the surrogate decision-makers in public positions will know only that, in this case, automotive air pollution occasions discomfort and harm and that alternative means of reducing it cause various amounts of inconvenience. Even after identifying its priorities, a society still faces a difficult task in taking, in concert with its public officials, the actions implied by those goals.

To attain effective pursuit of our priorities, it is essential that the societal system as a whole be regarded. We must examine the policy levers that exist, understand the constraints upon their use, foresee their consequences, and investigate the creation and formulation of new policy possibilities. Too often, attention has focused upon isolated parts or upon parochial aspects of the encompassing system. Ecologists have announced their imperatives but have not explained their conclusions and reasoning adequately either to the voter or to the public official. Economists have promulgated elegant incentive systems for restoring the environment but have not learned from environmental experts the critical parameters of the situation nor from public officials and lawyers the obstacles to the implementation of their proposals. Lawyers have formulated codes to protect the environment but without enough consultation with hydrologists, toxicologists, and atmospheric chemists to know what most critically must be protected nor with enough economic understanding to avoid gross inefficiencies. Public officials have not bothered to assimilate the insights of environmentalists, economists, engineers, and lawyers to back measures that better achieve the goals of society or to administer in the best way existing programs.

We have argued above that the natural environment should be perceived as an interwoven net of systems. We argue here that an allied perspective should be applied to the entire meta-system consisting of natural and human components. As in nature, actions taken within small sub-systems can redound and have an ultimate net effect contrary to the original aim. Some sub-systems are amenable to change, others are impervious and unbending, still others are fragile. As in natural systems, great care must be given to the search for and identification of handles that can be used to manage human systems in accordance with social priorities. Certain levers will achieve greater absolute change per unit of effort than will others; some have highly random effects; yet others may be employed with fine precision. More attention should be devoted to comprehending the total chain of effects pursuant to the exercise of public options. The remainder of this paper will consider various options open to societies to control better their environment and will discuss factors that bear upon the choice among them.

The Dangers of Excessive Complication

A qualification is needed before leaving this section. The theme of our argument to here has been that we have managed our environment less well than we might have because the vision of our managers has been bounded. Analysts and researchers have been limited by their disciplinary expertise, officials are blinkered by neatly delineated responsibilities, all of us are blinded by the salient features of this moment's crisis. We have posited many instances in which a wider comprehension would lead to wiser actions and to superior results.

It has not been argued that all problems require intricate understanding of all remotely relevant systems. Whenever understanding of a pollutant mechanism is limited to its local aspects, management of its effects on a regional scale will be impossible. While we would urge study into its geographically broader effects, we could not expect competent regional management to precede that study.

We have argued that actions of environmental impairment should be treated analytically and governmentally on as broad a scale as their consequences. Governmental organizations may, however, enable corrective environmental actions only locally and not at the country or international levels. In such cases, the second best solutions of narrower scale management should be pursued even as efforts to eliminate the organizational constraints are underway.

The practitioner of systems analysis knows well how the introduction of extraneously related factors toys with the fine lines between the feasibility and infeasibility of his modelling--either for his own comprehension or for computation. All important systems features of a medium-sized city cannot be included in a simulation exercise based upon contemporary technology. The crux of the analytic problem then is not simultaneously to bring to bear all possible perspectives and insights. It is rather to take the broad view before the problem is simplified for the sake of feasible solubility. It is to judge which factors can be excluded--at least temporarily--from consideration and which can be treated in simplified fashion. When the modelling or the analysis has been completed, sensitivity checks should investigate the importance of effects omitted. When such a methodology is followed, conscious and careful extension of perspective by the scientists and public officials concerned with environmental problems will help them better to understand, to manage, and perhaps to resolve them.

III. MAKING THE SYSTEM WORK BETTER

The Unregulated System

We will here examine a simplified model which provides one way to conceptualize the social and economic chain of causation affecting the environment. For the moment, we will consider its processes in the absence of governmental intervention. Our goal will be to demonstrate the interconnectedness of the system activities, to expose shortcomings in the unregulated processes, and to identify system nodes where governmental action may most beneficially be applied.

The Transmission of Demands

This meta-system is diagrammed in Figure 1. The initiation point for its processes is in the node at the upper left-hand corner where the demands of society are formulated. The demands shown in this diagram are restricted to the economic realm of goods and services that can be bought and sold. Excluded here are the desires for more pleasant surroundings which--like feelings of security or filial affection--are not to be obtained in the marketplace. In the terminology of input-output economics, this box represents final demands--those goods and services sought for themselves and not demanded as inputs for the production of others.[4]

The social demands are transmitted to the economic sectors which seek to meet them. Like the citizenry which poses the final demands, these sectors are composed of many minute parts working in concert only as prodded by the economic mechanism of prices. We distinguish among households, industry--assumed to include agriculture--and government. The government here is merely a provider of such goods and services as transportation modalities, communications, and waste disposal. Its organizational and regulatory functions are for the moment excluded. The three sectors depend jointly upon each other in meeting the requirements placed upon them --a dependence indicated by the lines interlinking them. The joint capabilities of the sectors will determine the extent

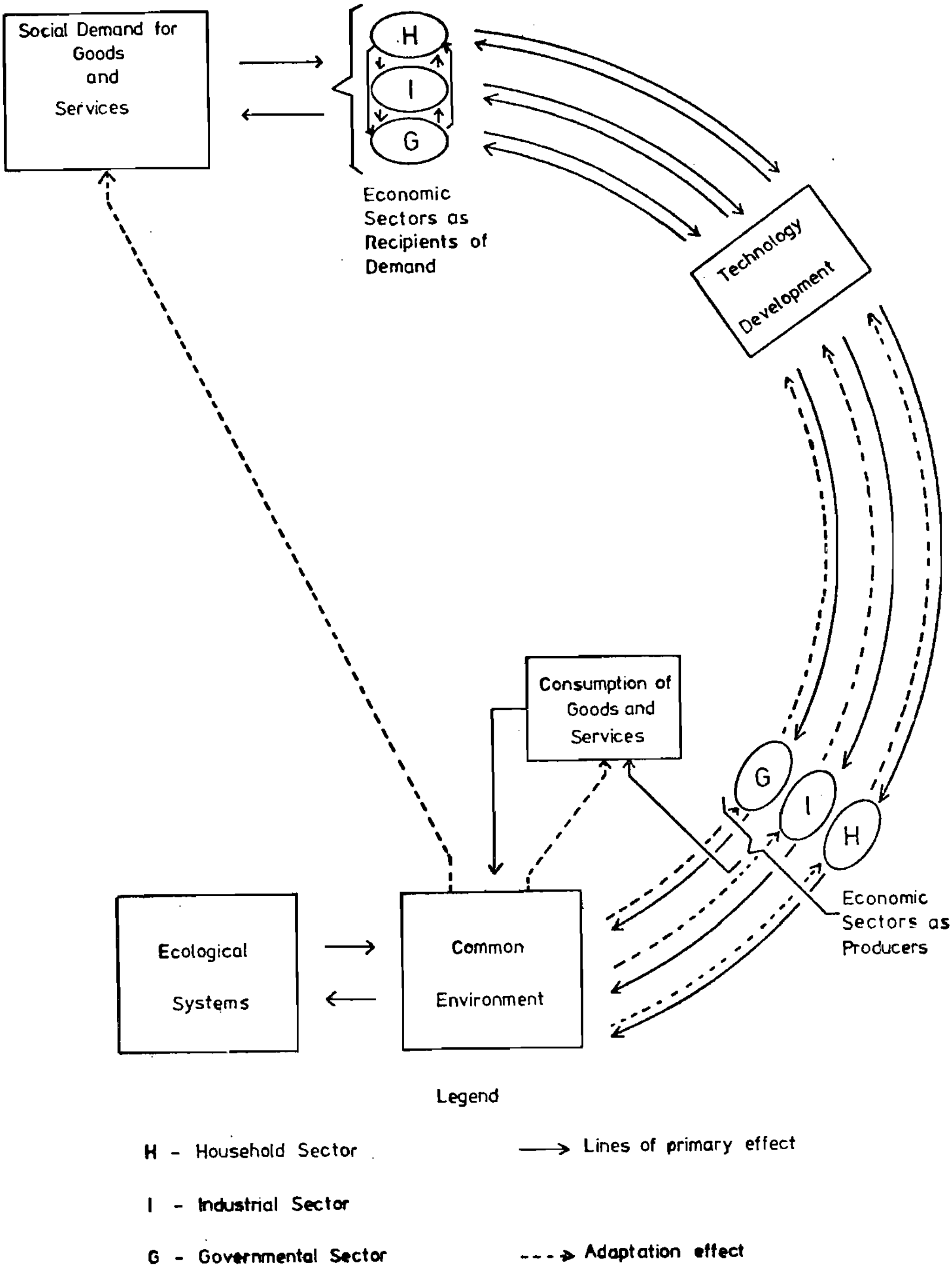


FIGURE 1

THE SOCIAL AND ECONOMIC SYSTEM AFFECTING THE ENVIRONMENT to which they can satisfy the demands and may lead to a modification of the demands--illustrated by the arrow leading back to the demand box.

New Technologies, Production, and Consumption

Each of the sectors may require the development of new technologies to meet the demands placed upon it. These needs are communicated to the developers of technology--the next box clockwise--as shown by the arrows to that box. Depending upon the capabilities of the technology developers, the technology demands may have to be modified--a process indicated by the arrows leading back to the sectors. These modifications may be further relayed back to the original node of social demand.

When the technologies have been made available to the three sectors, they are adopted by individual productive units. This process is indicated by the solid lines drawn downward and clockwise to the sectors--here represented as producers. The output of the sectors goes--following the solid arrow to the left--to final consumption of goods and services. Here again the distinction of input-output economics is made: consumption for the sake of subsequent production takes place within the three producing sectors; consumption as an end in itself occurs at its own separate node.

Environmental Effects

The processes of production and consumption inadvertently create pollution as the by-products of their activities are absorbed by the common environment. The polluting process is portrayed by the solid arrows from the producing sectors and final consumption to the environment. The distinction is made between production-related pollution and that derived from consumption. The former would include automotive air pollution caused by cars bringing workers to the factory; the latter would cover the exhausts of car travel for recreation.

The common environment--or "commons"--is the receptacle of all the pollutant effects resulting from human or natural processes. Inside of this node occur all the synergistic reactions of various pollutants. The systems of nature, shown to the left of the environment, must adapt to their surroundings--however altered by human processes. Because ecological systems also effect the environment, at times detrimentally, this effect is indicated by the arrow back to the environment.[5]

Adaptation

From the impairment of the environment, a degree of adaptation by the human system ensues. The sectors producing and consuming adjust to imperfect surroundings. The adjustment is illustrated by dotted lines leading backward to these nodes. An example of activity alteration indicated by these lines would be the increased use of pesticides to compensate for growing immunity of insect populations. From here, further adaptations may occur. The altered modes of production and consumption may lead backward to demand technologies better suited to operating or living within a polluted environment --a process also indicated by a dotted arrow. Thus new filtration technologies may be sought by industry for the intake of polluted waters and demand may be generated for home air-conditioning processes that will eliminate various toxic compounds and particulates. Neither of these adaptations is designed to improve the environment, but both enable more comfortable and efficient subsistence within it.

The third important mode of adaptation is through the effect of the environment on the demands of society at the initial node. There may, for example, be a shift from outdoor to indoor activity. The dotted line indicating this effect closes the loop of the system. Again this adaptation does not alter activities to enhance the environment, but instead seeks to improve the existence of the component micro-economic parts. Each of the myriad minute sub-systems of the three economic sectors and of the demanding society makes its own isolated adjustments to the impaired environment. The net effect of these adaptations may have net disbenefit to the system. Thus, the reactions to urban air pollution may be increased demand for air-conditioning or be longer commuting to work to live outside the smog. These adaptive processes themselves may lead to so much more pollution as to leave society worse off than if no adaptations had been made.[6]

The Flaw

The glaring defect of this system is the familiar one of economic externality effects or system sub-optimization. Each of the millions of systems components maximizes over its own desires and processes. But, because one's own environmental damage is a minor cost to oneself, each pays minimal attention to the harm he does his environment. The body of those injured by environmental damage is so large and diffuse that no reaction is possible within the system limned above. Even when governments perceive the problem, the difficulties in identifying the injured, in measuring the harm done them, and in organizing remedial action are enormous.

The remaining sections of this paper shall take the system we have just described as the conceptual basis for prescribing remedies to the environmental crisis. Our problem will be to investigate modifications in this system which will rectify the basic problem of neglected externalities by the sub-systems. We will seek the most efficient and rewarding ways to bolster the system through governmental intervention. In so doing, we will remember the processes described above. Governmental intervention that fights the natural activities of the system--which are powered by motives of self-interest --becomes thereby less feasible. Favored will be those actions which take advantage of the underlying mechanisms and incentives of the system and those which complement the system by explicit compensation for its weaknesses.

Handles

From the Technological Viewpoint

Cursory reflection upon the environmental problem reveals three primary ways in which the pollutant by-products of technological processes or their effects may be curtailed:

1. by reducing the magnitude of polluting activities;
2. by modifying the activities so that they pollute less; and
3. by better distributing pollutant emissions so that they cause less harm.

We have argued that the pollutant saturation of increasingly larger geographical systems renders the third alternative less feasible now for many forms of discharge than it has been in the past. Once the technological processes are completed, three additional strategies for mitigating their pollutant effects are available:

1. treatment of pollutants in transit to parts of the environment;
2. treatment of polluted environmental systems; and
3. adaptation to an impaired environment.

Together these six methods provide our basic repertory for action to improve life within the environment.

Within the Social and Economic System

An examination of Figure 1 indicates many nodes at which various combinations of the six basic policy measures may be applied. At our original node, governments may take actions to reduce final social demand. At the next node clockwise, restrictions may be placed upon the economic arrangements effected to meet the demand. The technology development node offers the opportunity for governmental constraints, for direct action via research in government laboratories, and for manipulating the incentive structures of the technology developers. When the technologies are implemented, a wide range of policy measures can guide the mode of their installation, and their management in use. Similarly, the magnitude, timing, and location of consumption may be improved at the next node to the left. Along the lines running from the nodes of consumption and production, wastes may be treated on the way to their primary point of decomposition or absorption. This is mainly possible in flowing water. Reduction of pollution in the environment itself is possible and will be dealt with at greater length below. Natural systems may be mobilized to improve the environment and, finally, governments may spur the processes of adaptation.

A Partial Inventory

To go into greater detail about the specific policy tools available at each node would, for this paper, be excessive. As many tools are applicable at several nodes, we simply list here modes of governmental action that can be taken to improve the environment, grouped under five broad headings:

1. Direct action: management of environmental systems; guidance of the systems run by the government, such as the transportation network, to minimize the harm done the environment; performance of research and development activities; preparation for remedial action in the event of emergencies; initiation and support of institutions such as medical clinics and swimming pools enabling better adaptation to an impaired environment;
2. Compellence of action: use of formal injunctions, prohibitions, enjoinders, and rationing procedures;
3. Manipulation of incentive structures: implementation of taxes, subsidies, price supports, fines, and bonuses to redirect the actions of producers, consumers, and developers of technology;
4. Creation of new organizational forms: establishment of a market for pollution rights; adoption of new judicial procedures enabling easier litigation against despoliation of the environment; subsidization, as in

providing low cost legal counsel for citizens aggrieved on behalf of the environment; creation of formal arrangements to enable polluting parties to coordinate and time their discharge to reduce environmental damage; and

5. Public education: to explain the consequences of acts against the environment; perhaps to campaign for a modification in individual tastes and preference structures;[7] to request voluntary abatement of specific activities.

The list is necessarily incomplete but nevertheless indicates the range of policy option available to the society firmly intent upon improving its environment.

> Recommendation 8: The direction of research and development for the amelioration of the environment should be influenced by consideration of the social processes through which the advances sought will effect their benefits.

Technological breakthroughs whose implementation is infeasible have doubtful value. Just as the reorganization of economic and government processes to protect the environment should be guided by available technology, so research activities should preferentially seek out areas where the receptivity and needs of existing social systems enhance their potential value. The remainder of this paper will discuss more specific means by which this may be achieved.

Incentives

Their Effects upon Policy Options

The individual components of the conceptual system we have described--the demanders, producers, researchers, and consumers--are guided by the dictates of self-interest. This motivating principle must be heeded as a government seeks the node in the process at which its intervention would be most effective. There are many well-intended actions which would achieve no practical result because the individual microeconomic units are not motivated to respond to them. An example would be promoting the development of less polluting technologies either through direct action or by subsidizing such research in existing laboratories. If such actions alone are taken, no practical impact will occur since none of the producing or consuming units will have reason to adopt the techniques developed.[8] Our model of the social system thus indicates that sponsorship of activities to develop less polluting techniques should be accompanied by measures to motivate implementation.

On the other hand, it may be possible to take advantage of the self-interest mechanisms and to intervene at one node with consequences that improve the entire system. The standard economic example of such an action is imposition of a pollution tax at the points where environmental discharges are released by producers and consumers. The amount of the tax per discharge should equal the amount of harm done the entire society by the discharge.[9] The polluting units will then be motivated to reduce their activities to the point at which the gain they obtain at the margin from the process creating the pollution equals the tax. They will also: 1) make improvements in their own implementation of machinery to reduce their emissions and to distribute them better; 2) demand less polluting technologies from the developers; and 3) raise their own prices to reflect the tax imposed upon them which will in turn induce a decrease in the social demand for goods and services that entail environmental damage. But this elegant solution of economics founders upon two practical problems: 1) that the tax will fall more heavily upon some than upon others and will therefore be resisted; and 2) that the information required to set the tax equal to marginal social harm--the optimum level--may be difficult or impossible to obtain. We shall consider both of these problems in sections below.

Incentives for Adaptation

The process of adaptation to a damaged environment illustrates both the policy insights available through the consideration of incentive structures and the pitfalls that lurk when they are considered in isolation. Purely on grounds of incentive, there is no reason for a government to intervene here. The self-interest of producers, consumers, and sufferers alike will lead them to what is for each individually the optimal level of adaptation. Their demands for adaptive technologies will moreover be transmitted to the developers of technology.

But we cannot absolutely dismiss the rationale for governmental activity here. Public education may be required to disseminate information on specific environmental hazards and on recommended ways to reduce them. Research and development traditionally require significant capital investments as well as the will to innovate. If either lacks in existing social units, governmental initiative may be required. Advances in knowledge that are not subject to patent rights or to market exchange may not be pursued by private firms. An example of this is the search for optimal behavior patterns in an impaired environment. Governmental action may therefore be required. Finally, governmental measures restraining adaptive processes may be needed if the processes themselves contribute significantly to impairing the environment.

> <u>Recommendation 9:</u> Research and development efforts should be guided with recognition given to the incentives impelling individuals.

This is corollary to Recommendation 8. Our talents and energies should, ceteris paribus, be directed toward projects for which incentives exist to disseminate the results and toward areas which private developers of technology have not had motivation to investigate. Policy analysts would do well to explore further the possibilities for innovative manipulation of the incentive structure for the betterment of the environment.

Equity

A Political Model

In the system we have displayed so far, the explicit role of the government as rectifier of environmental wrong has not been delineated. We now modify Figure 1 to illustrate better the mechanisms of governmental intervention, its causes and consequences. In Figure 2, the producing and consuming sectors and the developers of technology are coalesced into one node, that of operating systems. Ecological systems are here assumed part of the environment. The identical arrows of interaction are assumed except that the distinction is no longer maintained between primary and adaptive processes.

When the environment becomes less pleasant to inhabit, it gives rise to public response which in turn may effect governmental action. This chain of events is shown by the

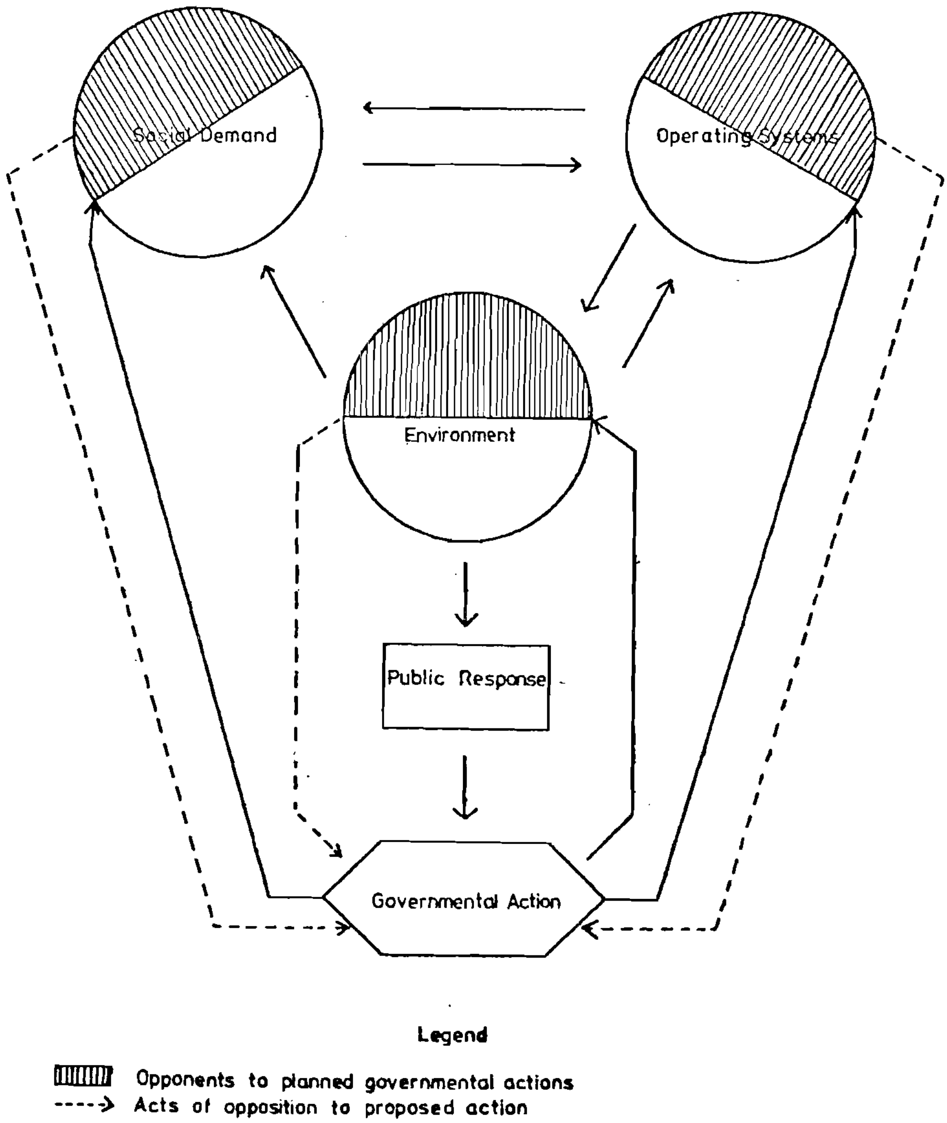


Figure 2

The System of Government Intervention in the Environment arrows leading downward from the environment to the two nodes below. Public response may take such forms as demonstrations, literature distribution campaigns, and constituent pressure upon elected representatives. Governmental action encompasses all the measures discussed in the preceding section. As we have seen, it may be applied at any of the three top nodes and is indicated by the solid arrows leading from governmental action to these nodes.

Any potential corrective action taken by the government will inevitably benefit and harm certain segments of the population more or less than others. We have accordingly distinguished in Figure 2 between the losers from the actions and those who either gain from or are indifferent to them. The prospective losers in each of the three nodes at the top are indicated as shaded portions of the nodes.[10] These areas may represent elements in the social demand who do not want to give up large cars, or factories that fear the expense of technology modifications, or residents of a geographical area where a new metropolitan airport is planned. Not unnaturally they oppose planned actions that will leave them worse off than before and their opposition is indicated by dotted arrows aimed back to the governmental seat of action. Less often the opposition may be directed toward nullifying the public outcry.[11] When the offended parties are sufficiently organized and powerful, they may block the proposed action, or modify it, or postpone it indefinitely. This systems mechanism should be borne in mind as strategies for environmental protection are selected.[12]

> <u>Recommendation 10:</u> Research and development should heed the political realities that may impede the implementation of their results. This again follows from the eighth recommendation. This explicitly implies that more attention need be given to research efforts to produce less expensive anti-pollution techniques, to enable better management of the environment, and to guide preparation for environmental catastrophes.

Technological breakthroughs certain to be blocked by powerful political interests are diminished in value. Research advances that can achieve beneficial social impact without exciting strong opposition should, ceteris paribus, be preferred. It may be wise as specific projects are being pursued to carry out simultaneously a campaign to educate the public about forthcoming technologies. This may increase public demand for their adoption and reduce potential opposition. Policy analysts should investigate ways to introduce environmental measures with injury to as few people as possible and with minimal injury to those who are hurt. This may require the working out of cheat-proof schemes for compensating the losers.

Low-Cost Technologies

An important step in mitigating the injury to polluters required to adopt new technologies would be to reduce the cost of the technologies. This may be accomplished by subsidizing the adoption of the techniques or by sponsoring research to obtain less expensive versions of the technology. For political reasons, more support should perhaps be given to research designed to reduce the costs of anti-pollution technologies than would be justified on strictly economic grounds.

Environmental Management

A strategic approach to the environmental problem explicitly favored by consideration of political mechanisms is that of managing polluted systems. The advantage is that direct action of this type requires few individuals in the society to modify their behavior.[13] An additional gain is that it enables broad-gauge access to the pollutant system instead of the fractionated approach required when attention is paid to point source polluters. This enables consolidation of effort and avoidance of the cumbersome informational problems involved in monitoring many point discharges. The area of environmental management offers the opportunity for the innovative development of many new technologies with high likelihood of immediate and valuable implementation.[14]

Emergency Preparation

One direct action in environmental management meriting special attention is preparation for emergencies. In every governmental system the rare catastrophic event plays what often seems a disproportionate role in inducing system change.[15] In the environmental area this is perhaps the more appropriate because much of the danger in our alterations of ecological systems inheres in such occurences--in the chances we run that the rare drought will enable the polluted river to become especially toxic or that the rare windless spell will make our air pollution lethal. A less dramatic risk is that continual abuse of the environment may lead to unstable behavior by ecological systems or to their dislodgement into less favorable equilibria. The organizational problems involved in coping with environmental emergencies are of such magnitude that only governmental authority has the potential to take effective remedial action.

The range of policies that may be adopted to reduce the severity of environmental emergencies is broad. Direct action against the polluted system may be possible through such measures as the neutralization of acids or the use of detergents to emulsify spilled oil.[16] In instances of extreme air pollution, modification of the weather to blow away or to precipitate out toxic pollutants becomes an attractive policy. When environmental catastrophes appear imminent, immediate prophylactic action--as in restricting transportation, or energy use, or untreated sewage releases--may be advisable. In times of high environmental health hazards, special medical units might be activated to treat the ailments that can be expected to arise. After a disaster has seriously injured an ecological system, the adoption of special policies designed to speed the return to the status quo ante--such as the importation of certain plant and animal species--may be beneficial.

All of these potential areas of activity merit further exploration. For environmental engineers this is a vast domain for important technological advances. Governments need to know what measures are available to deal with specific crisis situations, how the measures should be implemented, what the complete range of consequences to be expected from their application is, and what the attendant uncertainties are.[17]

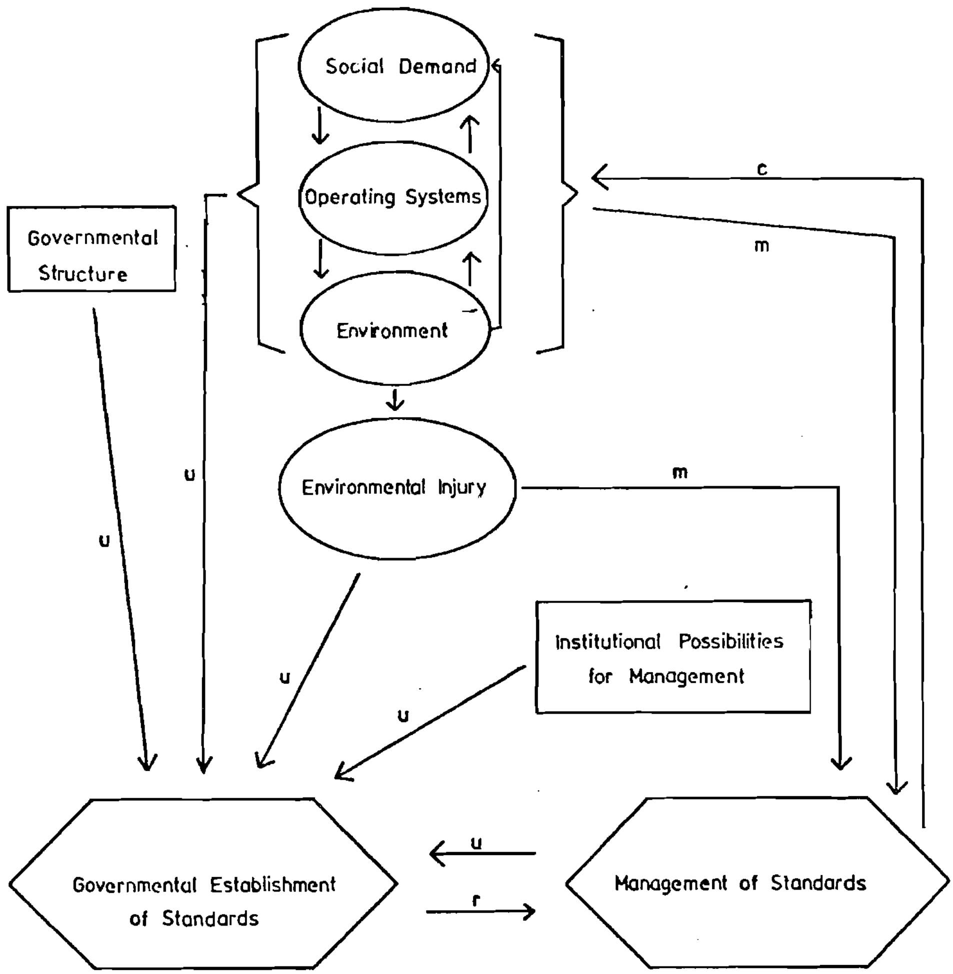
All of the governmental options require precise information on the extent and characteristics of the impending or actual catastrophe. Although this same information is needed by individuals who wish to avoid hazardous activities in a dangerous environment, only the government is placed to gather, evaluate, and disseminate it efficiently. More research is necessary to find less expensive and more efficient ways to learn when to warn against strenuous outdoor activity or eating shellfish as well as when drastic precautionary measures are called for. The following section will give more attention to the informational problems of the governmental authority committed to protecting the environment.

Standards

Information Flows and the Concept of Standards

We have so far mentioned only fleetingly the informational problems required to maintain environmental quality in an efficient way. In Figure 2, we presented simplistically the mechanism through which governments are impelled to act. That diagram ignored, however, the informational problems to be surmounted if the actions taken are to be wise. For explicit consideration of the informational transfers required for competent environmental management, we display one such system of flows in Figure 3.

The top three nodes in this diagram are our familiar social system abstracted from Figure 1 and here drawn linearly for representational convenience. The system processes are unchanged. The effect of environmental damage is shown in the next lower node as environmental injury--whether to humans, to other life, or to earth systems interpreted more broadly. The sense of injury is in turn transmitted to the government which may or may not take action. We have in this chart recast in terms of their underlying rationale the actions the government may take. We suppose the measures adopted by the



Legend

$\xrightarrow{c}$ Transmission of control actions
$\xrightarrow{m}$ Transmission of monitored information
$\xrightarrow{r}$ Investment of resposibility
$\xrightarrow{u}$ Assimilation of understanding

Figure 3

Information Network for Environmental Management

government to have the objectives of achieving or maintaining certain levels of environmental quality. Whichever of the options mentioned above is adopted--whether it be taxation, direct action, or injunctions--should be linked in the mind of the government with the goal it is expected to attain. Such goal levels we shall henceforth refer to as "standards." Even less direct actions, such as the facilitation of litigation by environmental plaintiffs, require established notions of adequate environmental quality--standards--to serve as judicial guidelines.

Setting and Maintaining Standards

The establishment of standards is an involved and intricate matter. It may be done poorly on merely a sense of environmental aggrievement. Or it may be based upon outmoded toxicological arguments reasoning through simplistic statistical analysis. To achieve a rational, functional, and consistent set of standards requires that they be set with comprehension of:

1. the governmental structure--its processes, power groups, and impediments;
2. the social systems polluting the environment;
3. the institutional possibilities for managing the environment--these depending in turn upon existing technologies; as well as
4. the nature, extent, and causal process of environmental injury.

This fourfold dependence is shown by arrows marked "u" from each of the corresponding nodes to the node at which the standards are established.

Once a set of standards has been established, the responsibility for enforcing them is delegated to a functional agency. This assignment is indicated by an arrow marked "r". The departments responsible for maintaining environmental quality as prescribed in the standards require continual, periodic monitoring of the systems producing pollution and of the environment. This ongoing information need is fulfilled by the transmission of monitored information and is illustrated in the diagram by arrows marked "m". This data is then interpreted in the light of the established standards and is used as the basis for issuing day-to-day control instructions to the polluting system. Figure 3 depicts these by the arrow labelled "c" which represents such actions as changing the tax on the use of high-sulfur coal, regulating the discharge of untreated sewage, shutting down certain factories, and warning children against outdoor play. After experience has been gained in the administration of standards, it should be reflected in their modification or in the adoption of new standards. This process is illustrated by an arrow marked "u" leading from the node managing the standards to the node enacting them.

Recommendation 11: The network of information flows serving both short-term and long-term decision processes merits close scrutiny as we lay plans to protect our environment and as we select the targets for our research and development efforts.

The Information Gaps

The system we have diagrammed is an idealized one. Much of the understanding and factual knowledge required to operate it optimally is not presently available. Policy-setters often lack sufficient time to assimilate the knowledge that we do have. Both technical and analytic experts can, however, do much to improve the information flows so that the social system works better. They should redirect their own inquiries to obtain information of highest priority to the system and, as we argued in Recommendation 7, they should learn how better to communicate their findings and insights to citizens and public officials. Research into technical and organizational means of improving the feedback from social systems and the environment to the enactors of the standards is especially urgent. We must also recognize that many crises of the moment require action long before the ideal body of information is available. It is important for policy analysts to improve the methodology for making decisions that necessarily are based upon imperfect information and are subject to large uncertainties. We shall examine in greater detail two of the processes by which information is acquired for decisions.

Understanding Environmental Injury

We have drawn in Figure 3 the linkage between environmental injury and the enactment of standards as a simple arrow of understanding. The ideal information to be transferred here is impossibly enormous and complex while the actual information flow is deplorably inadequate. In the best of all worlds, we should understand the mechanisms of the polluting processes, the seriousness of the harm wreaked by the environmental damage, and the results that alternative policies would have in reducing this harm. How far short of this we fall can be seen in the enactment of air quality control standards.

One Area of Imperfect Comprehension

What we do know about air pollution is that it is unpleasant, unsightly, and, in certain circumstances, pernicious to human beings, animals, crops, and inorganic materials. We do not understand the connection between human health and long periods of exposure at relatively low concentrations to various pollutants. Existing epidemiological data is confounded by the myriad factors that bear on any given situation. Experiments with animals are flawed by the difference in physiological systems and by the use of concentrations far in excess of typical ambient values. From each of these potential sources of scientific clarification, much conflicting advice is received. Problems of expense and ethics have meanwhile prevented the use of controlled experiments upon men. We do know that ozone and sulfur dioxide are harmful but do not know the pathological mechanisms through which they work.[18] There are growing indications that certain particulates are carcinogens but this remains unproven. So far we have been unable to differentiate among the effects of many pollutants with the result that our standards cannot focus upon the critical compounds. Pollutants with such disparate effects as methane and benzene have been lumped together in the category of hydrocarbons. We do not understand the process of human adaptation to residual amounts of foreign substances in the body. We do not know the relationship between long-term and short-term physiological adaptations and, as a result, do not know the seriousness of temporary exposures to various pollutants. In the physical environment, we still do not understand many synergistic mechanisms--such as the role of carbon monoxide in smog formulation--as well as the sink processes for many compounds.

The Decision Node and its Values

Figure 3 shows the point at which standard-setting decisions are made as a neatly bounded box. In fact, the body of persons influencing the decisions is diffuse and ill-defined. A group of public officials may have nominal responsibility, but to varying degrees in the course of time they will be prodded by their superiors and by other governmental branches and agencies; they will be pressured by constituents; and they will delegate responsibilities to technical experts. Somehow, all of those party to the decisions must acquire the information necessary to guide their constructive inputs to the process.

Even when a necessary minimum of technical information has been received, it must be carefully interpreted in the light of social value judgments before suitable standards can be set. A common fallacy is the supposed universality of standards. It is too seldom recognized that standards for emission releases in a given climate and social context may be inappropriate in another situation. The customs and activities and priorities of a locale should be reflected in the standards it adopts. The society placing a high premium on certain heavily polluting activities may well set its thresholds of pollutant tolerance higher than another. If, of two jurisdictions, one considers aircraft noise to be an intolerable blight while the other senses it as a minor nuisance, there is little basis for insisting that their noise abatement standards be identical. To enable the individual tastes and values of a society to be reflected in the standards it imposes upon itself, it is necessary to communicate as well as possible technical dimensions of the problem situation to the societal decision-makers. This we have urged above.

It is the role of technical experts and analysts, in partnership with public officials, to identify the information needed to establish standards and to initiate steps for its procurement. Until the distant day when all desirable information is at hand, these groups must work together to fashion standards based upon the current comprehension of the problem and on the prevailing value structures. It is possible in the light of the information we have now to redirect the thrust of existing standards toward the most critical of environmental parameters and to improve enforcement mechanisms so that their objectives are more efficiently achieved.

Monitoring

The short-term management of the environment depends vitally upon the availability of monitored feedback information --indicated by the arrow marked "m" in Figure 3--to the managers. In this area technical experts and systems analysts can each contribute much to improving the efficiency of monitoring networks. New machinery and laboratory methods are needed to improve the praxis of environmental measurement and to tailor it to the critical variables incorporated in standards. When feasible, new variables should be developed. Social researchers have found that the decibel scale alone is a poor gauge of the discomfort caused by noise. Biological oxygen demand (BOD) may be the best single indicator we have upon stream quality but it is not without defects. For many purposes more differentiation is required among the types of organic nutrients. Perhaps a more serious shortcoming is that its measurement requires a five-day wait that severely lessens its value as a guide for day-to-day management. The monitoring process can be significantly strengthened by the development of methods to reduce delays in the feedback of monitored information and by the isolation of new variables which better capture critical aspects of the environment.

The potential contributions of analysts to environmental monitoring are many:

1. When monitoring the complete spectrum of important information is infeasible or prohibitively expensive, methods should be developed for basing management upon the information that can be obtained;
2. Means of applying new technologies--such as satellite observations--to obtain environmental feedback should be studied.
3. Meteorologists and probabilists should join efforts to determine the information set enabling accurate forecasts of environmental events;
4. Since the sweeping calls for monitoring from environmental advocates too often ignore the factor of cost, analysis should indicate the appropriate extent of information-gathering activities. Careful cost-benefit analysis of marginal additions to

monitoring networks is needed to determine the number of monitoring stations and the roster of variables to be observed. In this exercise, the linkages of specific bits of feedback to specific control activities should be heeded; and

5. Continual monitoring designed to assure compliance of polluters to emission and effluent standards can prove impossibly expensive. Game-theoretic analysis may be commissioned to develop more cost-effective methods based upon random samplings instead of perpetual observation.

IV. INTERNATIONAL PROBLEMS OF THE ENVIRONMENT

All the impediments to effective environmental management at the local, regional, and national levels are operant also at the global level. Global problems are, moreover, rendered especially intractable by their sheer physical scale and by the dearth of appropriate agencies for action. If we are to avoid catastrophes of international scope, an irreducible set of responsibilities must be assumed. Appropriately placed existing agencies--such as the United Nations Environmental Program (UNEP), Unesco, and IIASA--must each assume those tasks best suited to its competence and jurisdiction. But this may not be enough. Vital additional responsibilities that have not yet been taken up may require the extension of mandate for present institutions or the creation of new organizational nodes.

Institutional functions which, we argue, must be performed include:

1. Providing a focal point for the understanding of such global environmental problems as contamination of the oceans with heavy metals and radioactive materials, acid rains, albedo changes, atmospheric turbidity, and carbon dioxide concentration;
2. Coordinating environmental research--enabling the perspectives of individual disciplines and nations to be aggregated into a fuller picture without undue duplication of effort;
3. Assisting individual nations and their decision-makers to understand the technological dimensions --possibilities, constraints, and implications-- of environmental problems; and
4. Providing a forum for coordinating interest in international problems of the environment so that broadly desired concerted actions may be taken.

When these roles are filled analysts and managers will be better able--working systematically together--to understand and to attack our common problems of world environment.

Footnotes

[1]Good examples of such composite technologies are the techniques being developed in Israel and Pakistan for the conjunctive use of ground water.

[2]It can be argued that many of our long-term environmental problems are exacerbated by the fact that public officials elected for the short-term have little incentive to remedy them.

[3]This is not wholly the fault of analysts but can be blamed also upon the incentive environment in which they operate. The analyst who admits to uncertainty is neither heeded nor rewarded.

[4]Conceptually, this distinction is useful. Operationally, the differentiation between consumptive and productive activities of the household--between eating to live and living to eat--has caused many headaches.

[5]As this is an adaptive process, the arrow might be dotted. We have drawn it as a solid line because of the primary nature of this effect on the ecological systems. It is to be hoped that recognition of the harm done ecological systems per se--and not just as it indirectly affects man--will guide our protection of the environment.

[6]Further adaptations--adaptations to the adaptations--could be drawn in. Because they are attenuated and would clutter further the diagram, they have been omitted.

[7]This must be done in a limited way and with care--a possible example is urging motorists to prefer smaller cars. Impossible philosophical arguments are stirred up if we admit our value structures to be the prime determinants of policy and then attempt to alter those structures.

[8]If the new technologies are less expensive for production, they should have been developed without reference to the environment. Since they were not, we assume they are more costly.

[9]This is the marginal damage caused and should take into account all injured parties, on a global basis if necessary.

[10]It is possible that disgruntled parties include winners who feel they should have won more--for instance those who wish a proposed swimming pool to be closer to their home.

[11]This mechanism is not illustrated.

[12]Examples of the difficult problems that may arise are connected with the disposal of waste heat. Farmers--especially vineyard owners--may oppose the use of wet cooling towers. Use of flowing waters may heat them significantly and destroy prevailing ecological systems. Whether the new ecological systems that would inhabit the hotter river are better is problematic. Hotter waters would lead to greater speciation which in turn would render the ecological systems more stable. On the other hand many large game fish would be threatened with the effect that this solution is strongly opposed by fishing interests.

[13]Even so, problems will arise. A Japanese colleague reports that extreme pressure was brought to bear upon environmental planners who recommended that an oxygenation plant be built in a densely populated residential area.

[14]One example here is the development of electro-osmotic processes for purifying entire systems.

[15]It is difficult to estimate the influence that the air pollution disasters in the Meuse Valley in 1930 and in London in 1952 have even now in the minds of relevant decision-makers.

[16]Unfortunately many cures of this type--as the detergents used to fight the Torrey Cannon oil slick--create problems of their own. Much more research is needed both to develop new remedial technologies and to understand their far-reaching effects upon natural systems.

[17]The whole area of weather modification is presently plagued by tremendous uncertainties. It has been argued that such projects as hurricane seeding may have the disastrous long-term effects of impeding the natural latitudinal energy transfer and of sharply reducing total annual rainfall for various regions. We should work to resolve these uncertainties but proceed cautiously in implementing weather modification policies until the doubt is dispelled.

[18]Doubt is now even being cast upon the conclusion that sulfur dioxide was the culprit in the London smog disaster of December, 1952.